Manufacturing Demonstration of a Large-scale, Multi-material Passenger Vehicle Sub-system

Project ID: mat243

DOE Vehicle Technologies Office Annual Merit Review, Online, June 21 - 23, 2022

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Overview

OVERARCHING PROJECT GOAL

Implement a systems approach to redesign and manufacture a high-volume 2019 mid-size Honda SUV's glider system to achieve cost-effective and sustainable light-weighting through component consolidation, state-of-the-art optimization tools, multi-material joining methods, industry-standard manufacturing processes and recycling technologies while meeting or exceeding baseline performance.

TIMELINE

- Start: October 1st, 2021
- End: December 31st, 2024
- Level of Completion: 15 %

BUDGET

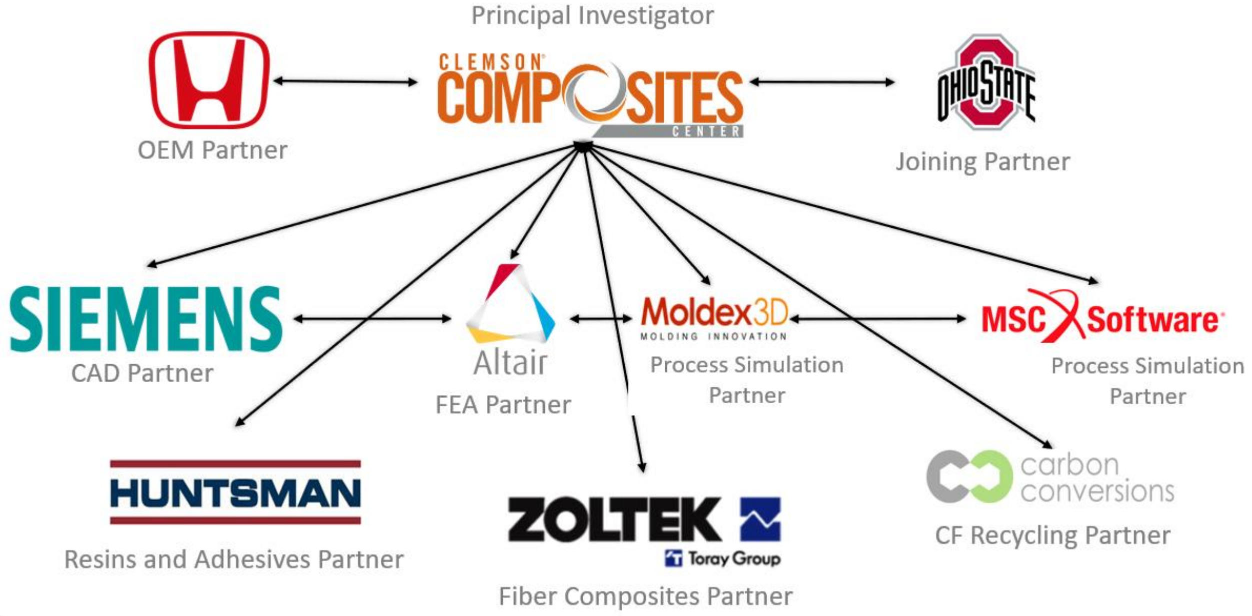
Total Project Funds: $ 11.5 Million

- $ 5.75 Million – DOE
- $ 5.75 Million – Cost share

BARRIERS IN ACHIEVING PROJECT GOAL

Cost-performance tradeoff	• Identifying the trade-off between composites and traditional metals for cost-effective redesign • Using composites while enabling fast manufacturing cycle times and preserving OEM's existing joining & assembly infrastructure • Achieving cost and light-weighting targets while meeting or exceeding baseline performance targets • Developing and integrating cost, sustainability, and performance predictive tools to identify suitable material systems and designs.
Material – Process – Property Integration	• Testing & characterization for material aging data cards development • Development of process data cards through manufacturing process experimentation – simulation loop. • Development and deployment of coupled ply-forming and resin infiltration model for Wet Compression Molding (WCM) • Developing compatibility between transition joints and WCM

PROJECT PARTNERS



Project Relevance

1. **Achieve a 160 lbs. (73 kg) weight reduction**
   - Aligns with U.S DRIVE Roadmap to enable weight reduction

2. **Zero compromise on performance targets**
   - No compromise in crash performance, NVH, durability, strength and stiffness
   - No compromise in the fit & packaging of other sub-systems

3. **Cost increment limited to $5 per pound (.453 kg)**
   - Allowable increase of **$800** per glider system

4. **Scalability**
   - Annual production of **200,000 vehicles**
   - Preservation/simplification of the OEM's factory assembly process

5. **Recyclability**
   - Utilize recycled carbon fiber to enable **sustainable light-weighting**

Milestones

BUDGET PERIOD 1 (1st October 2021 to 31st December 2022)

- ✓ Design Requirements completed (Q4 2021)
- ✓ Conceptual Designs completed (Q1 2022)
- ❖ Metal-CF Transition Joint Machine Adaptations completed (Q4 2022)
- ❖ Metal-CF transition joint modeling completed (Q4 2022)
- ❖ Down-selected Conceptual Designs meeting performance criteria (Q4 2022)

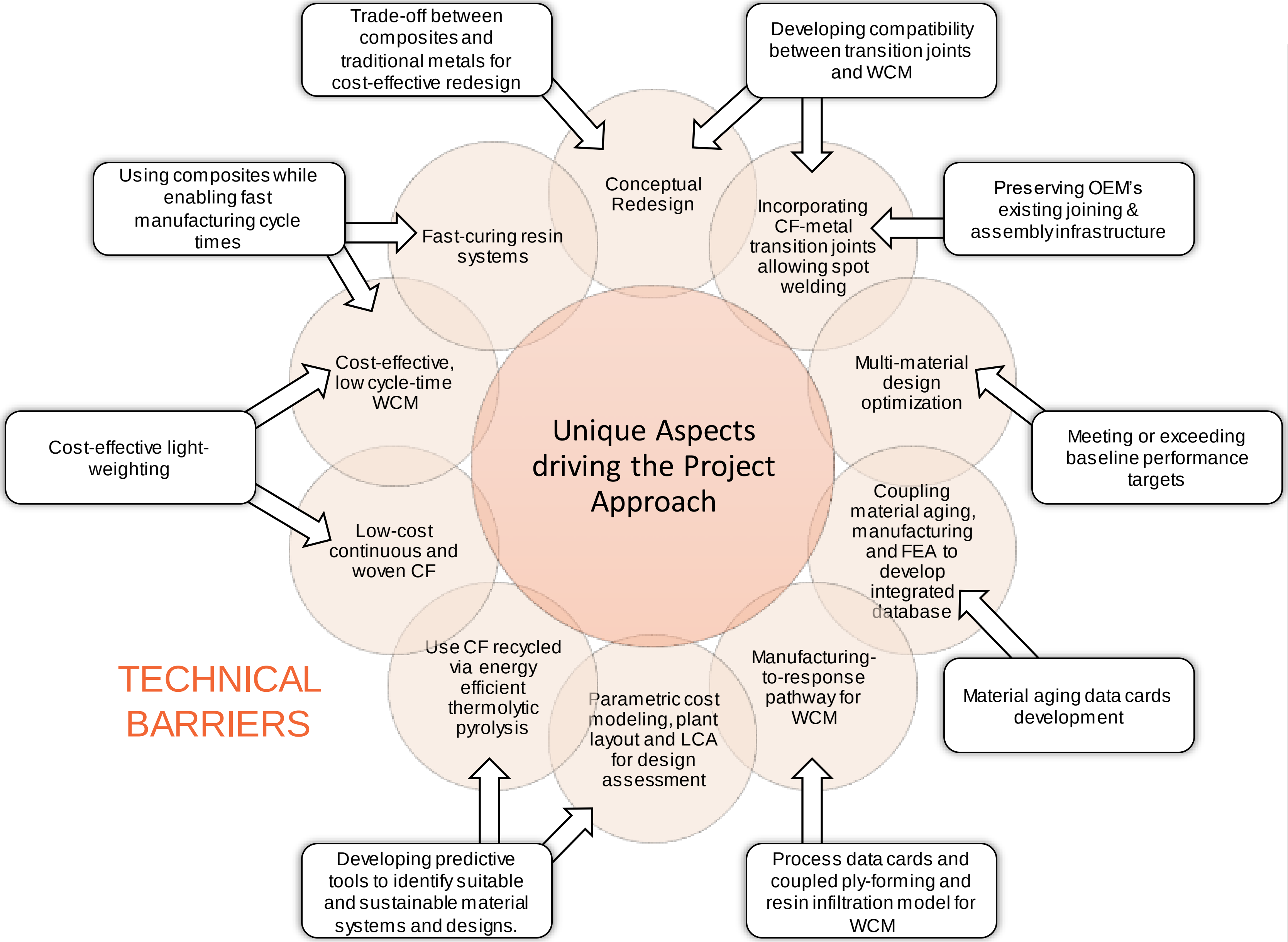
BUDGET PERIOD 2 (1st January 2023 to 31st December 2023)

- ❑ Metal-CF transition joints verified to meet performance criteria (Q3 2023)
- ❑ Corrosion and life-time prediction models validated (Q4 2023)
- ❑ Performance prediction validated (Q4 2023)
- ❑ Mock-up sub-system verified to meet fit and integration criteria (Q3 2023)

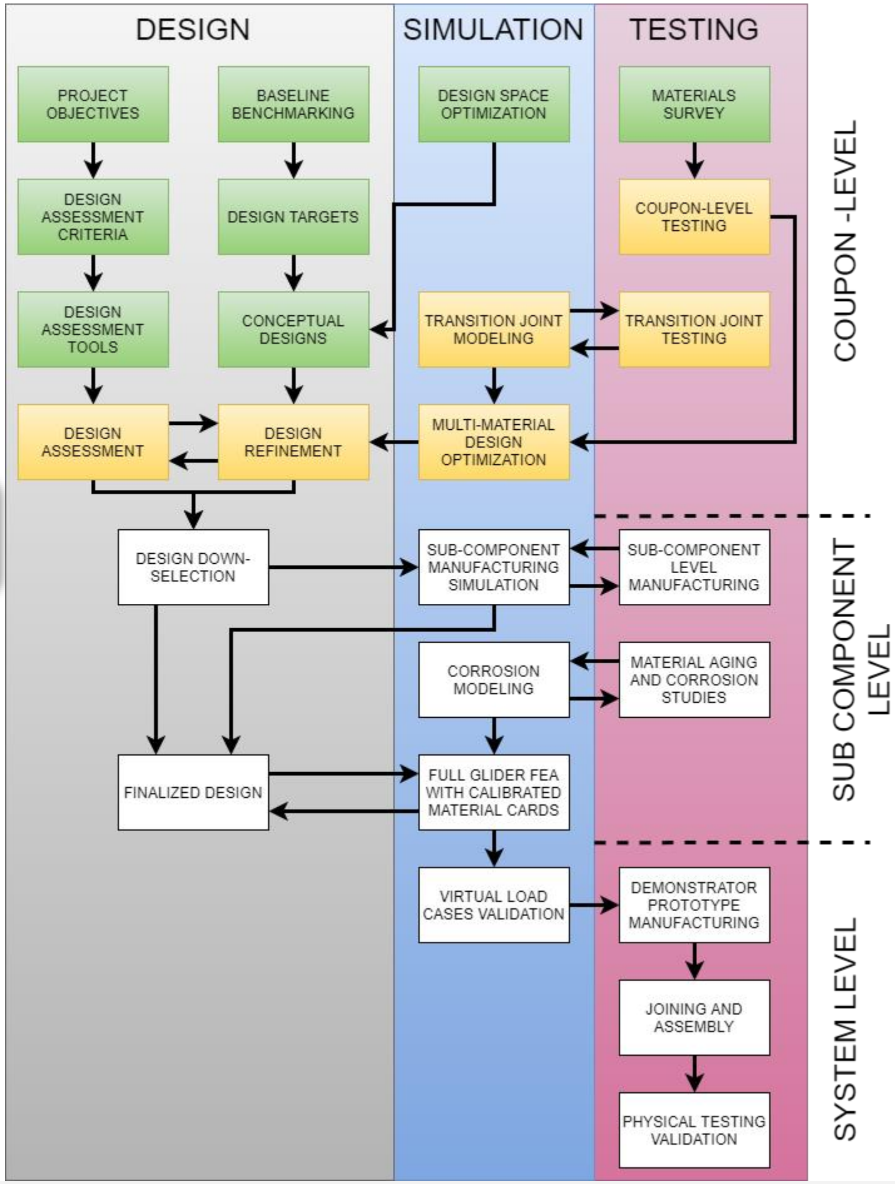
BUDGET PERIOD 3 (1st January 2024 to 31st December 2024)

- ❑ Factory layout completed (Q4 2024)
- ❑ Glider recycling strategy complete (Q4 2024)
- ❑ Glider assembly complete (Q2 2024)
- ❑ Glider performance tests complete (Q3 2024)

Project Approach



SYSTEMS APPROACH

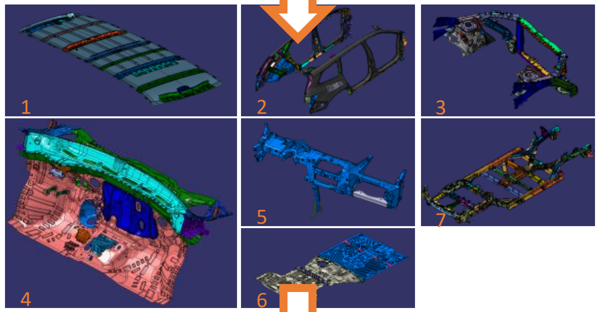


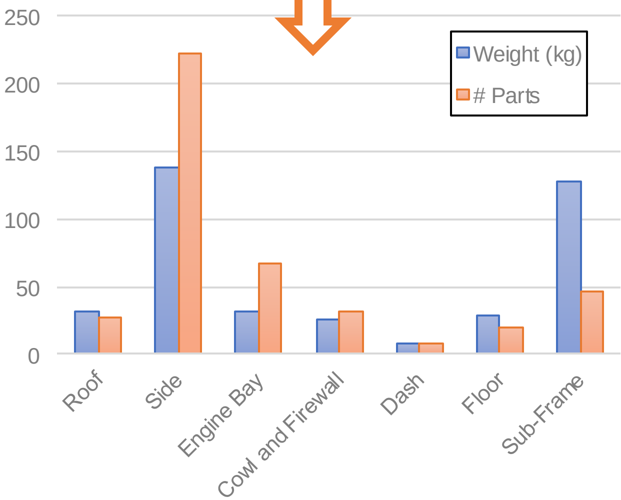
Progress: Concept Development

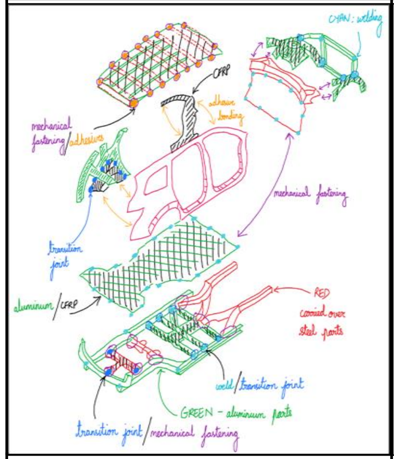
Materials
- Baseline Steel, Aluminum
- FRP thermosets (CF, GF, Basalt, Kevlar)
- FRP thermoplastics (CF, GF, Basalt, Kevlar

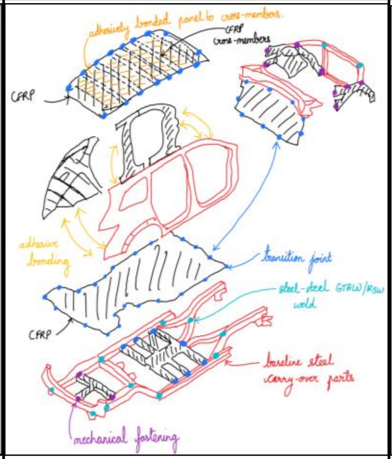
Manufacturing Processes
- Standard steel/aluminum sections
- HPRTM, WCM, SMC
- Thermoplastic Forming
- Injection Molding

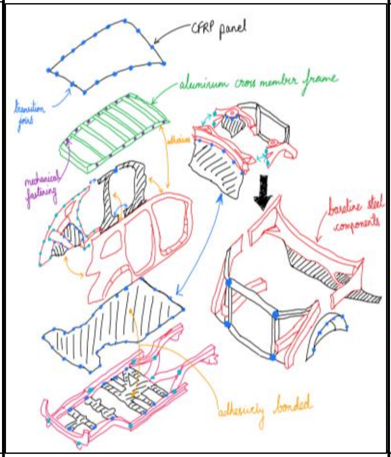
Joining Processes
- Mechanical Fastening
- Welding – RSW, MIG
- Adhesives – Adhesive bonding
- Transition joints

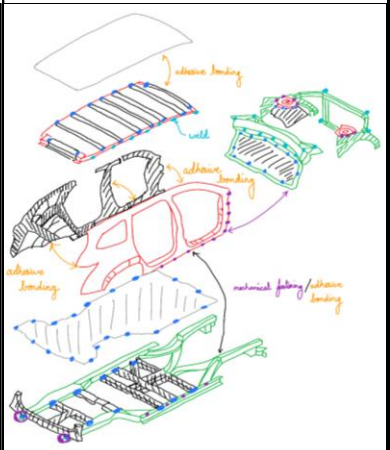


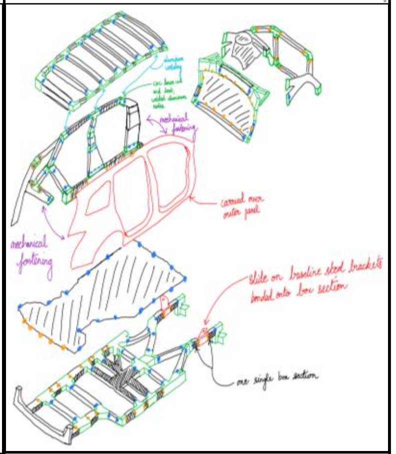






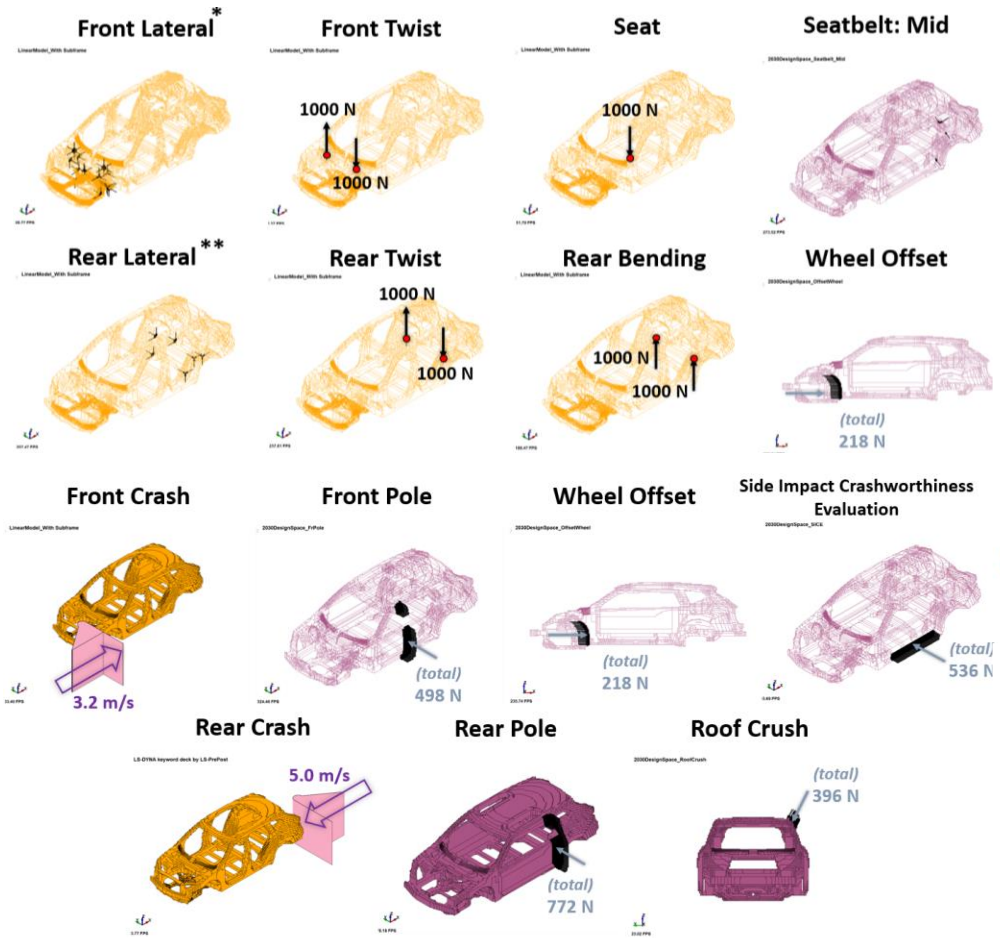


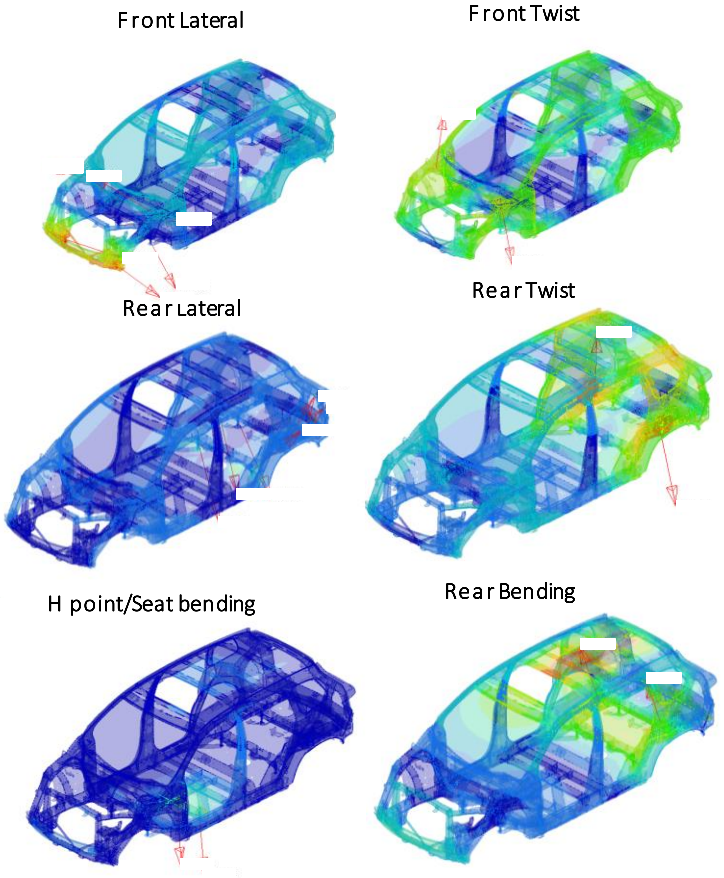




Concept 1	Concept 2	Concept 3	Concept 4	Concept 5
• Carry-over steel parts • major replacement with aluminum • selective parts consolidation with composites	• Carry-over steel parts • major parts consolidation with composites	• CFRP-steel construction with transition joints • CFRP-aluminum-steel transition joints for roof • Subframe outer members and mid-rails retained • Cross members and floor consolidated into a composite design	• Welded Aluminum sections as frames for composite panels • use of basalt fibers/GFRP for panels • Side panel and stiffener sub-assembly consolidated into single composite design	• Spaceframe with metal nodes • Adhesive bonding • RSW + transition joints leveraged • Favorable for prototype technology demonstrator glider
• Weight Reduction Potential: 17.4%	• Weight Reduction Potential: 27 %	• Weight Reduction Potential: 30%	• Weight Reduction Potential : 43%	• Weight Reduction Potential: 39%
• Parts Consolidation Potential: 21.75%	• Parts Consolidation Potential: 32.8%	• Parts Consolidation Potential: 30.5%	• Parts Consolidation Potential: 39.5%	• Parts Consolidation Potential: 41%
• OEM Assembly line compatibility: LOW	• OEM Assembly line compatibility: **HIGH**	• OEM Assembly line compatibility: MODERATE	• OEM Assembly line compatibility: MODERATE to LOW	• OEM Assembly line compatibility: LOW

Progress: Structural Performance





A summary of load cases and displacement contour plots for the considered baseline model.

Description of Load Cases considered

	Load Case	Description
1	Front Lateral	Lateral loading at front suspension points
2	Rear Lateral	Lateral loading at rear suspension points
3	Front Twist	Torsional loading at front suspension points
4	Rear Twist	Torsional loading at rear suspension points
5	Rear Bend	Bending load at rear suspension points
6	H point loading	Loading at seat mounting points
7	Front Crash	Small overlap front impact
8	Rear Crash	Small overlap rear impact
9	Side Pole Impact	Side pole loading near front/rear of vehicle
10	Roof Crush	Loading on the roof
11	Wheel Offset	Loading on front left wheel well
12	SICE	Side Impact Crashworthiness Evaluation (IIHS)

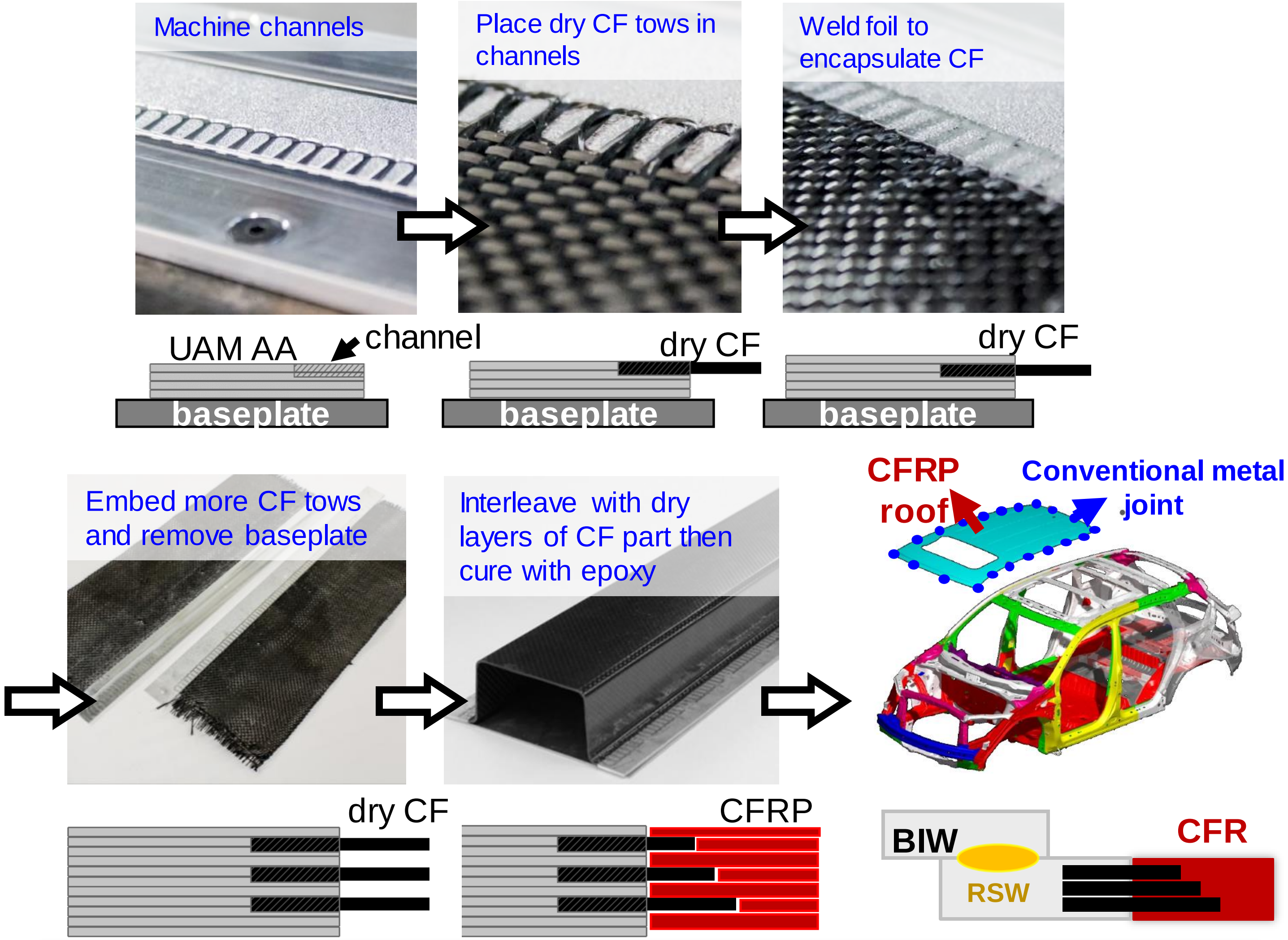
***Static Load Cases. (solved)**
***Dynamic Load Cases. (ongoing)**

Progress: UAM Process

OSU's UAM system with automated foil feeder and CNC

Tensile strength	CF: 102.3 MPa Al: 129.5 MPa
Cross-tensile strength	2318 N
Corrosion cycling	No degradation after 120 cycles
Axial crush	+66% EA* +97% efficiency
Four-point bending	+86% EA +83% efficiency
Torsion	+48% EA +13% peak load

* EA: energy absorption



Research on material combinations, design, and manufacturing integration to achieve light-weighting and cost targets while meeting strength, corrosion, and safety requirements

Collaborations

ACADEMIA PARTNERS	
OEM PARTNER	
GLOBAL N-TIER PARTNERS	
MATERIALS & RECYCLING PARTNERS	

Proposed Future Work

- Task 1.3: Cost, cycle times, plant layout and LCA
  - Assess, refine and down-select conceptual designs
  - Identifying process flows for LCA

- Task 1.4: End of life recycling
  - Identify opportunities to use CCI's recycled CF preforms in proposed conceptual designs
  - Incorporate CCI's process data into LCA

- Task 1.5: Transition Joint Development
  - Develop model for transition joints and incorporate into topology optimization
  - Develop material card for use in topology optimization using results from coupon-level transition joint model.
  - Complete UAM joint fabrication machine adaptations to meet cycle time requirements

❑ Milestone: Transition joint modeling complete (Q4 2022)

❑ Milestone: UAM machine adaptations complete (Q4 2022)

- Task 1.6: Multi-material Glider Optimization
  - ✓ Baseline FEA completed and results evaluated to establish complete set of design requirements/targets
  - Single material topology optimization
  - Multi-material topology optimization

❑ Milestone: Conceptual design meet performance criteria(Q4 2022)

Summary

- **Task 1.1 Glider design requirements - Complete**
  - ✓ Milestone: Design Requirements complete
- **Task 1.2 Systems design**
  - ✓ Milestone: Conceptual Designs complete
  - Design refinement and down-selection in-progress
- **Task 1.3 Cycle time assessment, cost modeling and LCA**
  - Methodology for Cost Model was developed
  - Design concepts assessment in terms of manufacturability and cost in-progress.
- **Task 1.4 End of life recycling**
  - Initial data from carbon conversions being assessed
- **Task 1.5 Metal-CF transition structure**
  - Coupon-level modeling using existing materials in progress
  - UAM metal-CFRP transition joint fabrication process and system being developed to speed up fabrication. Beginning research on transition materials and design for specific joining applications.
- **Task 1.6 Multi material design optimization**
  - Baseline FEA completed and results evaluated to establish complete set of design requirements/targets
  - Single material topology optimization in progress

Technical Back Up Slides

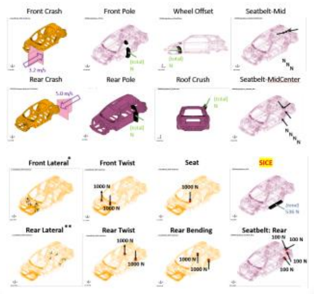
Cost Modelling

- **Objective:**
  - Develop a cost model that includes the cost of material, equipment, labor, energy consumed for the fabrication of all structural and non-structural parts of the glider.
- **Scope:**
  - Includes all processes, both at OEM and offline.

1. Fabrication of CF pre-forms.
2. Fabrication of Transition Joint.
3. Fabrication of final CFRP-metal components.
4. Fabrication of non-structural components.
5. Assembly of glider at OEM.
6. Post-processing of glider at OEM (Paint., etc)

Topology Optimization Workflow

Load Cases

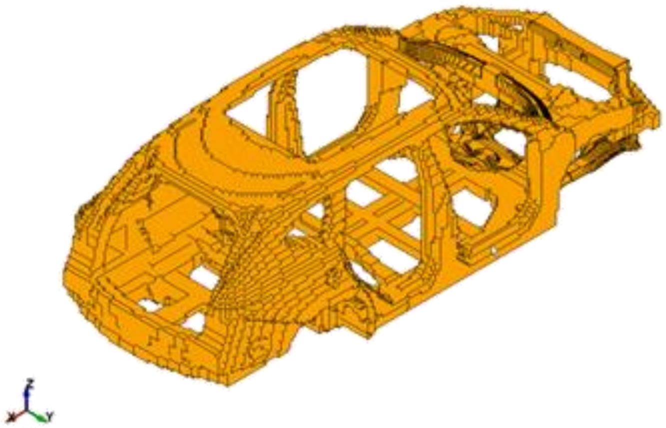


Displacements & Stresses

Updated Topology

Design Requirements

Current Topology



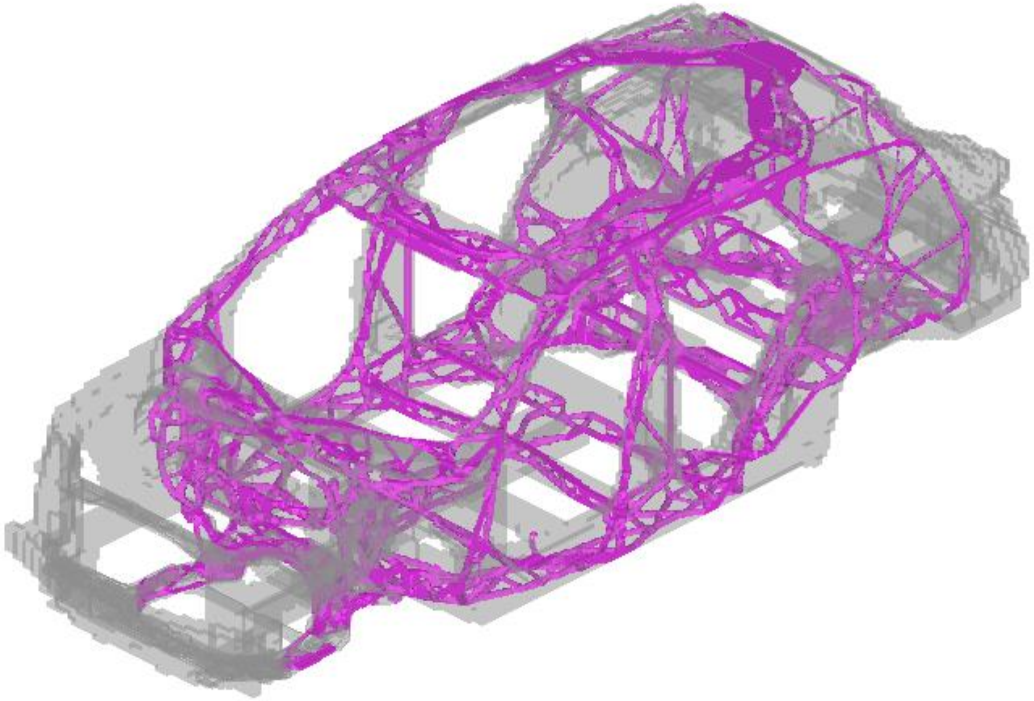
Topology Optimization

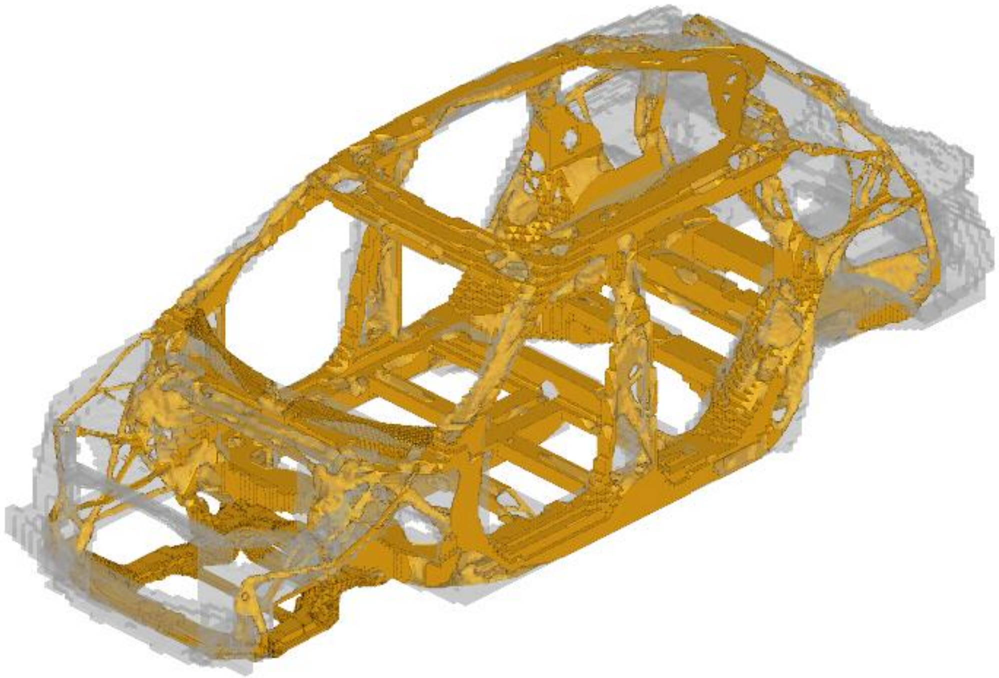
Optimized Topology(ies)

Altair® OptiStruct®

Single Material Topology Optimization Results

*Static cases only

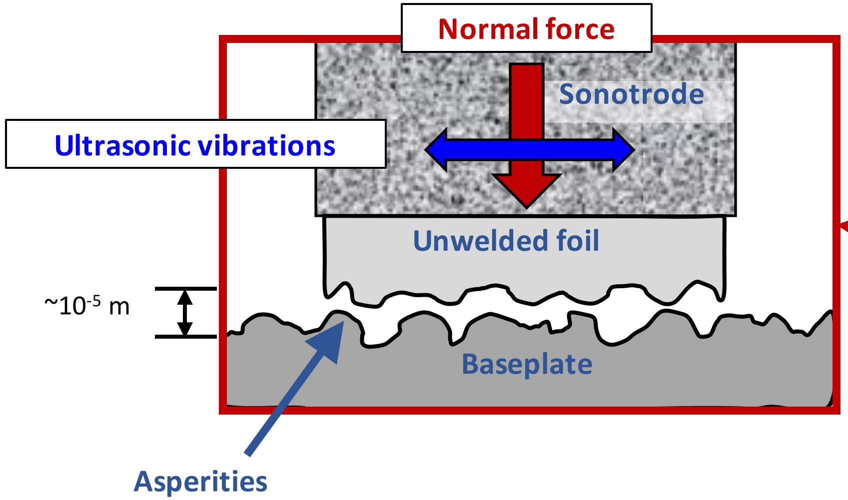


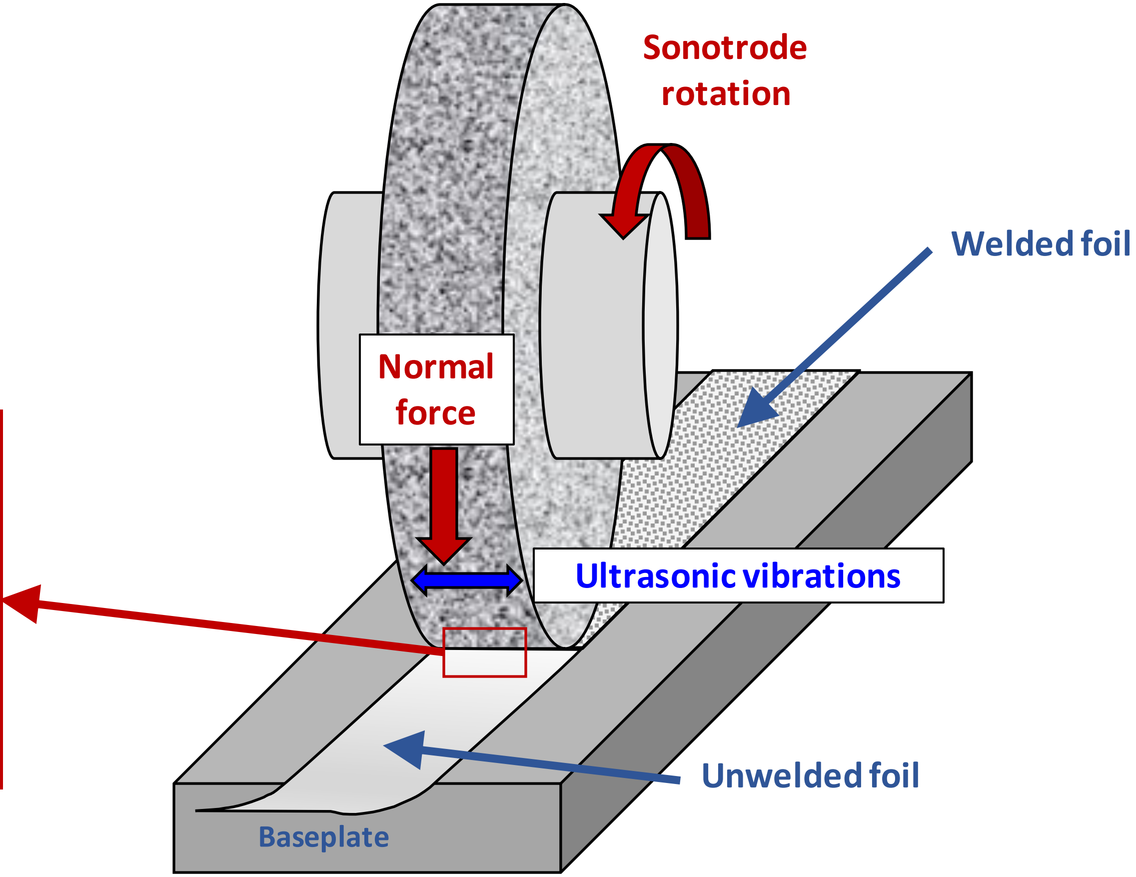


Objective	Min V	Min Σcompliance
Subject To	• Max stress constraint • Baseline compliance constraint	• Max stress constraint • 25% (of design space) volume constraint
Material	Steel	Steel

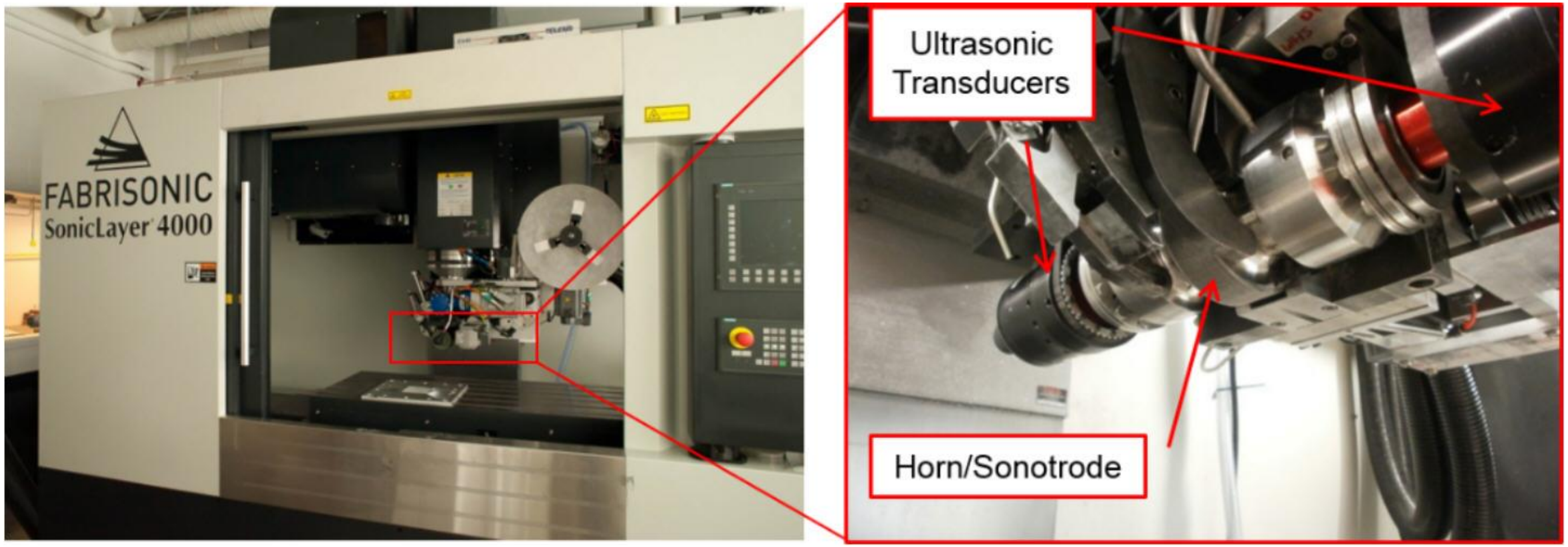
Ultrasonic Additive Manufacturing (UAM) - Process

- Ultrasonic additive manufacturing uses solid-state ultrasonic metal welding to create metal parts
- Dispersal of oxide layer and collapsing of asperities lead to metallic bonding
- Low-temperature process
- Unprecedented opportunity to embed temperature sensitive materials in metals
- Combined with CNC and laser can create near net shape parts





Ultrasonic Additive Manufacturing (UAM) - System

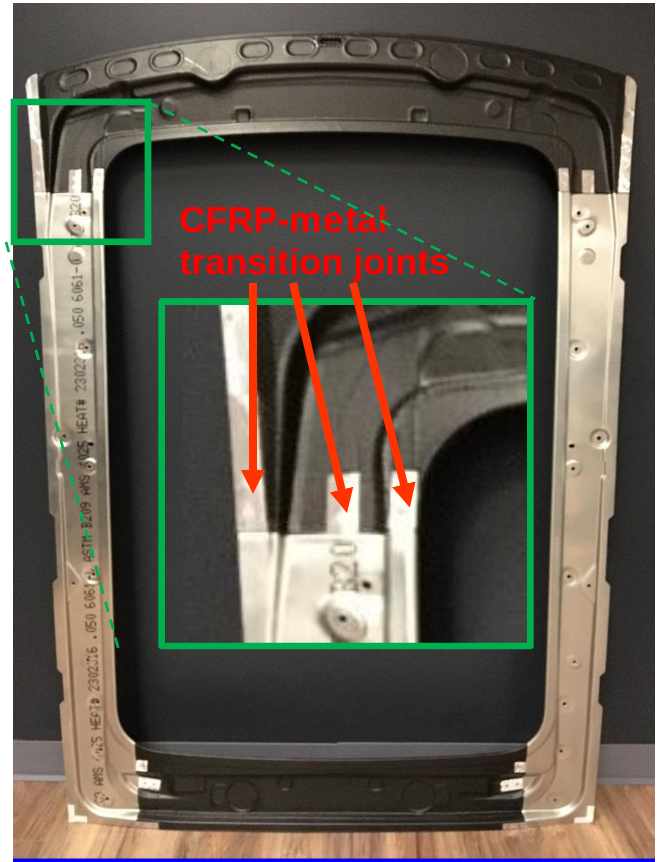


9 kW SonicLayer 4000 UAM system

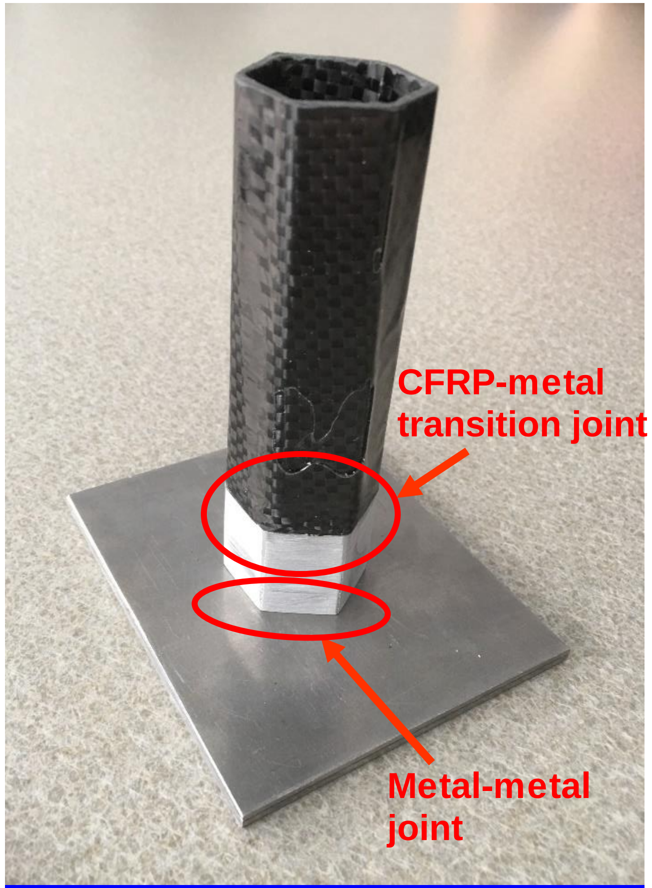
- 3-axis CNC mill with 25 HP, 8000 RPM spindle
- 1 m × 1 m × 0.6 m work volume
- 9 kW piezoelectric dual weld head and sonotrode for welding a variety of alloys including Al, Ti, and stainless steel
- 40 W integrated laser for micromachining, surface modification, and augmented embedding
- Automated feeder for metal foil
- Instrumented to record sensor data and input power during welding

Previous Results and Feasibility – Demonstration Parts

Since dry fibers are embedded in a choice of metals, virtually any CFRP part can be laid up with integrated metal tabs, ribs, or attachment points that can be joined to other metal structures using traditional metal-to-metal joining methods

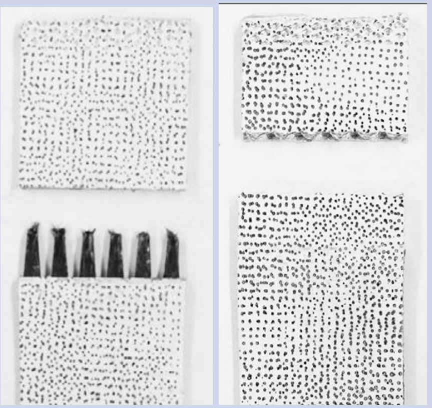


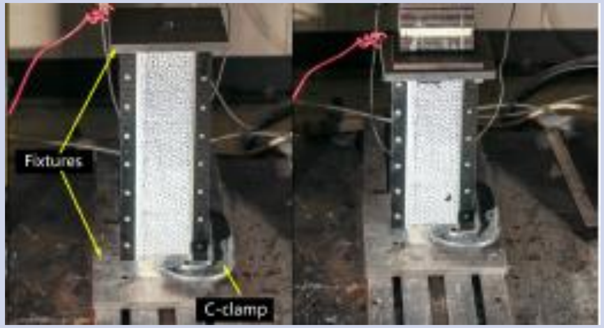
Aluminum and CFRP hybrid roof stiffener with UAM CFRP-metal transitions

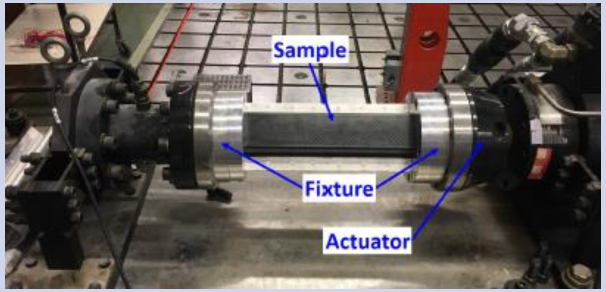


CFRP hollow rod with integral aluminum end connector, joined via UAM CFRP-metal transitions. End connector is attached to a metal base with a conventional metal-metal joint.

Previous Results and Feasibility – Key Test Results







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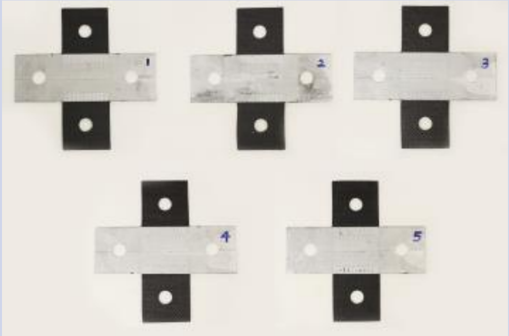
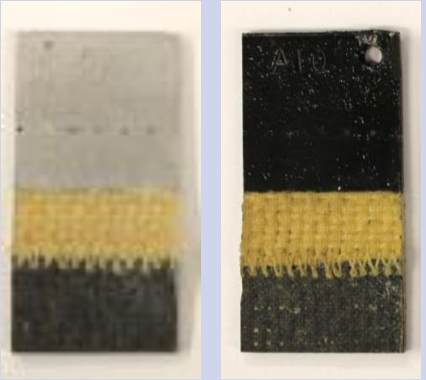
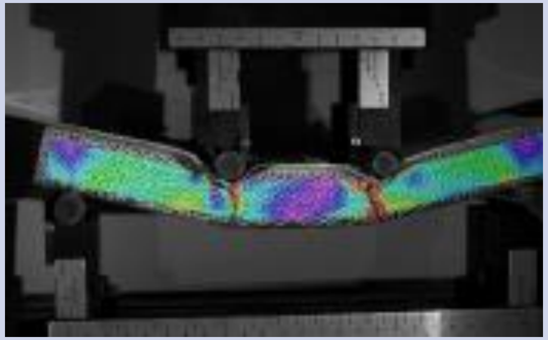






OSU-led Tasks

Task 5. Metal-CF transition structure development (M4-M24)

Perform detailed metal–CF transition joint development for fiber/fabric form choices, performance (tensile shear and cross-tension strengths), manufacturing approaches, joining and assembly options (spot welding or adhesives) and glider assembly to meet performance weight, cycle time, and cost goals

Task 5.1: UAM process adaptation (M4-M6)

- Adapt the UAM fabrication process to accommodate making steel-buffer-CF and aluminum-buffer-CF transition joints for glider sub-system structures over the course of this research program, including:
  - Designing and building a larger base fixture
  - Installing a high-speed spindle
  - Fabricating a tool to facilitate placement of loops in the machined channels.
- Evaluate cost-effective fabrics such as glass fibers (E, S) and basalt fibers as buffer materials, compared with Kevlar

Task 5.2: UAM process conditions (M7-M9)

- Conduct welding trials and shear strength testing to identify good welding parameters
  - Utilize automotive-grade aluminum and low carbon steel that are compatible with automotive RSW processes
- Build and test steel-buffer transitions to assess weld quality and mechanical properties

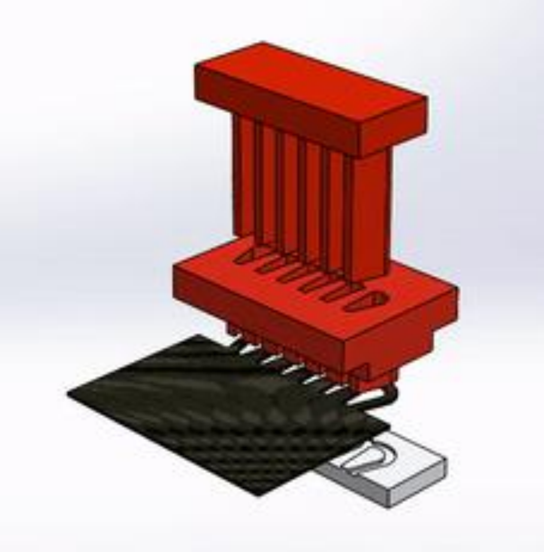
Task 5.3. Fabrication and characterization of metal-CF transitions (M10–M24)

- Fabricate samples for testing according to the design developed in subtask 6.2
- Test and characterize samples according to standard automotive company tests used by the automotive industry
  - Tensile shear strength (TSS)
  - Cross-tension strength (CTS)
- Representative structures or components will be fabricated and tested based on the simulated loading conditions from glider sub-systems and assembly-level simulations. These validation tests will help ensure that the transitions will perform as intended for multi-material vehicle gliders.

Progress: UAM Process

Ultrasonic additive manufacturing (UAM) system modifications to speed up fabrication of metal-CFRP transitions

Henninger Type-832 speed increaser selected (36,000 RPM continuous operation)



Fiber alignment device prototyped for faster placement of tows

OSU's UAM system with automated foil feeder and CNC capabilities